Making a Century in HERMIT

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Compilers Should not be Black Boxes

- We improve spam filters by scripting.

- Can we fix our compiler using scripting?

Remote Shell for our Haskell compiler?

- There is often a trade-off between the clarity and efficiency of a program.
- Useful to transform a clear program (specification) into an efficient program (implementation).
- This idiom has many instantiations: faster code; using a different interface; space usage; semi-formal verification.
- We want to mechanise such transformations on Haskell programs:
  - less time-consuming and error prone than pen-and-paper reasoning
  - no need to modify the source file
- Several existing transformation systems for Haskell programs, e.g. HaRe, HERA, PATH, Ultra. They all operate on Haskell source code.
- **We take a different approach, and provide commands to transforming GHC Core, GHC's intermediate language.**

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Demonstration: Unrolling Fibonacci

As a first demonstration, let's transform the *fib* function by unrolling the recursive calls once.

$$
\begin{aligned}
&\mathit{fib} :: \mathit{Int} \to \mathit{Int} \\
&\mathit{fib}\ \mathsf{n} = \textbf{if}\ \mathsf{n} < 2 \\
&\qquad\qquad \textbf{then}\ 1 \\
&\qquad\qquad \textbf{else}\ \mathit{fib}\ (\mathsf{n} - 1) + \mathit{fib}\ (\mathsf{n} - 2)
\end{aligned}
$$

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Demonstration: Unrolling Fibonacci

As a first demonstration, let's transform the *fib* function by unrolling the recursive calls once.

```
fib :: Int → Int
fib n = if n < 2
        then 1
        else fib (n − 1) + fib (n − 2)
```

```
fib :: Int → Int
fib n = if n < 2 then 1
                 else (if (n − 1) < 2 then 1
                                      else fib (n − 1 − 1) + fib (n − 1 − 2)
                      )
                      +
                      (if (n − 2) < 2 then 1
                                      else fib (n − 2 − 1) + fib (n − 2 − 2)
                      )
```

First Demo

First Demo

- resume ..... resume the compile
- `binding-of 'main` ..... goto the `main` definition
- `binding-of 'fib` ..... goto the `fib` definition
- `remember "myfib"` ..... remember a definition
- `show-remembered` ..... show what has been remembered
- any-call (unfold-remembered "myfib") ..... try unfold "myfib"
- `bash` ..... bash a syntax tree with simple rewrites
- `top` ..... go back to the top of the syntax tree
- `load-and-run "Fib.hss"` ..... load and run a script

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What did we do?

HERMIT requires a recent ghc (I am using GHC 7.8.3)

1. `cabal update`
2. `cabal install hermit`
3. `hermit Main.hs`

The `hermit` command just invokes GHC with some default flags:

```
% hermit Main.hs
ghc Main.hs -fforce-recomp -O2 -dcore-lint
            -fexpose-all-unfoldings
            -fsimple-list-literals -fplugin=HERMIT
            -fplugin-opt=HERMIT:main:Main:
```

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HERMIT Use Cases

- We want to explore the use of the worker/wrapper transformation for program refinement
  - We need mechanization to be able to scale the idea to larger examples
  - Medium-sized case study: Changing representations in the Conway's Game of Life
  - Are working on large case study: Low Density Parity Checker (LDPC), tansforming math equations into Kansas Lava programs
- HERMIT is for library writers
  - Authors show equivalence between clear (specification) code, and efficient (exported) code.
- HERMIT is a vehicle for prototyping GHC passes
  - Optimization: Stream Fusion
  - Optimization: SYB
  - Staging: Translating Core into CCC combinators. (Elliott, et. al.)
- Scripting Haskell-based Equational Reasoning – **this talk**
- (Your project goes here)

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Highest Level Architecture

We draw inspiration from UNIX and operating systems.

Three levels

- Shell Level ..... (UNIX Shell style commands)
- Rewrite Level ..... (UNIX man(2) system commands)
- Stratego-style library for rewrites ..... (DSL for rewrites)

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Shell Level

UNIX Shell style commands

- Dynamically typed, variable arguments
- Help (man) for each command
- Control flow commands (';', retry, etc.)

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Rewrite Level

UNIX man(2) system commands

- Haskell functions, strongly typed
- Think type :: `CoreExpr` $\rightarrow$ `M CoreExpr`
- Higher-order functions for tunneling into expressions
- Many function tunnel into GHC (example: substExpr)
- Allow, all GHC "RULES" are directly invokable.

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Stratego style library for rewrites

- Haskell DSL call KURE
- Basic idea: rewrites can succeed or fail
- Higher-order combinators for search, catching fail, retry
- Both levels reflect the Stratego API

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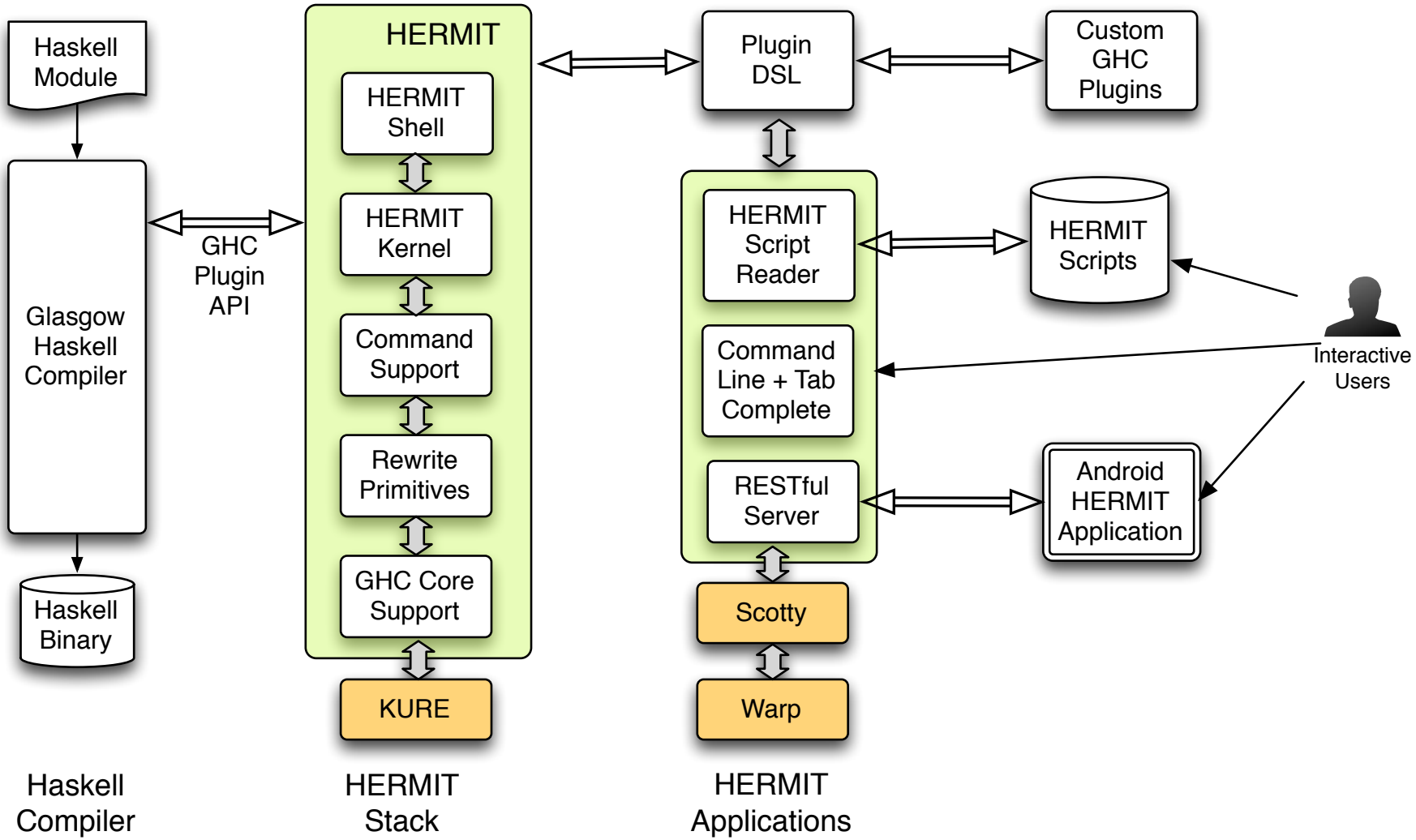
Lifting the Lid on the HERMIT Project



HERMIT Commands

- Core-specific rewrites, e.g.
  - beta-reduce
  - eta-expand *'x*
  - case-split *'x*
  - inline
- Strategic traversal combinators (from KURE), e.g.
  - any-td *r*
  - repeat *r*
  - innermost *r*
- Navigation, e.g.
  - up, down, left, right, top
  - binding-of *'foo*
  - app-fun, app-arg, let-body, ...
- Version control, e.g.
  - log
  - back
  - step
  - save "myscript.hss"

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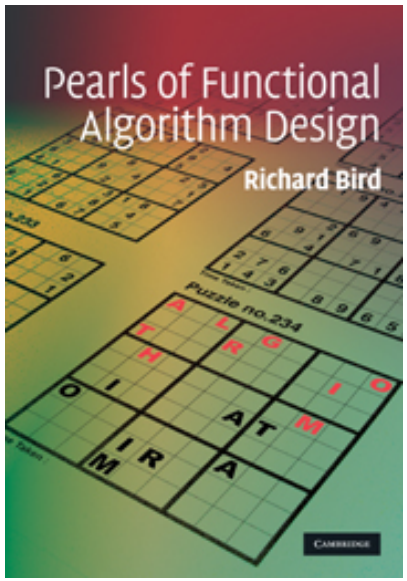
Pearls of Functional Algorithm Design



- The book is entirely dedicated to reasoning about Haskell programs, with each chapter calculating an efficient program from an inefficient specification program.
- We selected the chapter *Making a Century* from the textbook *Pearls of Functional Algorithm Design*.

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Larger Example: Deriving a better century

The program in *Making a Century* computes the list of all arithmetic expressions formed from ascending digits, where juxtaposition, addition, and multiplication evaluate to 100. For example, one possible solution is

$$100 = 12 + 34 + 5 \times 6 + 7 + 8 + 9$$

The derivation of an efficient program involves a substantial amount of equational reasoning, and the use of a variety of proof techniques, including fold/unfold transformation, structural induction, fold fusion, and numerous auxiliary lemmas.

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Fragment of the proof:

```
{ rhs-of 'solutions

  -- filter (good . value) . expressions

        { app-arg ; inline 'expressions }

  -- filter (good . value) . foldr extend []

        { [ app-fun, app-arg ] ; apply-rule "6.2" }
        { lemma "comp-assoc" }

  -- filter (good . value) . filter (ok . value) . foldr extend []

        { app-arg

          -- filter (ok . value) . foldr extend []

              { lemma "foldr-fusion-1" }

          -- foldr extend' []

        }

  -- filter (good . value) . foldr extend' []

}
```

GHC RULES

- GHC language feature allowing custom optimisations
- e.g.

{-# RULES "map/map" $\forall$ f g xs. *map* f (*map* g xs) = *map* (f $\circ$ g) xs #-}

- HERMIT adds any RULES to its available transformations
  - allows the HERMIT user to introduce new transformations
  - HERMIT can be used to test/debug RULES
  - We use the `[~]` syntax to record, but not use, a rule.

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What happened while deriving a better century

- During mechanization we discovered that several auxiliary properties in the textbook are stated as assumptions without proof.
  - we suspect that they are deemed either "obvious" or "uninteresting".
- Assumption 6.2 also had a simple proof, but it relied on arithmetic properties of Haskell's built-in `Int` type (specifically, that `m == n` $\implies$ `m <= n`).
- Two proof techniques are used in the textbook that HERMIT does not directly support.
  - The first is the fold fusion law, which needs implication, which we do not support.
  - The second involves postulating the existence of an auxiliary function.
  - We did manage to run the postulated function backwards, to verify the calculation.
- We have a plugin that provides the fold fusion law as a primitive.

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Length of Calculations for Century

Calculation	Textbook Lines	HERMIT Commands		
		Transformation	Navigation	Total
solutions	16	12	7	19
expand	19	18	20	38
Lemma 6.5	not given	4	4	8
Lemma 6.6	not given	2	1	3
Lemma 6.7	not given	2	0	2
Lemma 6.8	7	5	8	13
Lemma 6.9	1	4	4	8
Lemma 6.10	not given	23	13	36
Total	43	70	57	127

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HERMIT Summary

- A GHC plugin for interactive transformation of GHC Core programs
- Can express basic equational reasoning as HERMIT scripts
- New and powerful commands can be defined using a HERMIT plugin mechanism

```
cabal install hermit
```

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